EUROPA TRIPLE BANDS: GALILEO IMAGES. R. Greeley[1], R. Sullivan[1], K.C. Bender[1], K.S. Homan[1], S.A. Fagents[1], R.T. Pappalardo[2], J.W. Head[2], and the SSI Team, [1]*Dept. of Geology, Arizona State University, Tempe, AZ 85287-1404*, [2]*Dept. of Geological Sciences, Brown University, Providence, RI 02912*

Triple bands (TB) are linear features discovered on the Galilean satellite, Europa, during the Voyager mission [1,2]. TB consist of a central bright stripe averaging 1 to 2 km in width, flanked by two parallel low albedo stripes, each several km or more across. The average normal albedo of the dark component is 65% of the background bright plains [3]. Most ideas for the origin of triple bands based on Voyager data involve tectonic processes [4,5] in which the icy crust is fractured and intruded or flooded by material from the subsurface. Galileo imaging data [6,7] for triple bands were acquired on the initial orbits of the spacecraft around Jupiter and provide new insight into the characteristics and possible origin of these features. Data for TB were acquired on orbits G-1 at 1.6 km/pixel, G-2 at 6.9 km/pixel, C-3 at 420 m/pixel, and (possibly) E-6 at better than 30 m/pixel. Multispectral data were acquired on orbits G-1 and G-2. Analyses of these data suggest two new models for TB formation, one involving cryovolcanic processes, the other involving a rising thermal wave from the interior to the surface and dike injection.

Triple bands have a variety of morphologies, including the "classic" form described on Voyager images, forms which include irregular or discontinuous low albedo components, and forms which merge into solitary bright ridges or into solitary dark bands. In most cases, the low albedo components lack sharp outer boundaries and become progressively diffuse with the surrounding plains. In some TB, the central bright band formed later than the dark components, as evidenced by cross-cutting relations. Where some triple bands enter the terminator zone on G-1 images, the central bright band is seen to be a ridge; shadow measurements suggest ridge heights of about 30 m. Possible TB (or variations of TB) observed in C-3 images show that some bright bands consist of two parallel ridges separated by a central depression. In some areas the ridges are discontinuous, forming elongate segments or knobs >1 km across. The low albedo component is difficult to detect at the low sun illumination, but local dark patches ~1 km across are seen along parts of some ridges. We note that these features are smaller than classic TB; they could represent a different type of feature, or be a variation of TB. Another TB imaged in a second C3 frame provides important morphological information, as it was imaged essentially on the terminator. Here the central bright stripe is about 5 km wide and the band shows no expression of topography. The TB cross-cuts most surrounding features and shows a relatively sharp northern boundary, contrary to the diffuse boundaries seen in the G1 TB.

Multispectral imaging data suggest that TB consist of water ice containing an unidentified reddish component [3]. In G-1 data, the relative ages of TB can be determined from cross-cutting relations; the dark bands appear to brighten with time, assuming an albedo closer to that of the plains in which TB occur. Brightening could be attributed to: 1) changes in ice grain size, 2) progressive mantling by frost, 3) differential heating in which the dark, non-ice component absorbs more heat and sinks into the icy surface, becoming less visible, or 4) bombardment by magnetospheric plasma, changing the ice properties (e.g., creating a more porous surface layer) or inducing oxidation to brighten the dark materials (e.g., oxidizing S to SO_2).

The observations outlined above provide new insight into the possible origin(s) for TB. The diffuse outer margins for the low albedo component place important constraints on previous models. For example, models involving flooding of a graben [8,9] and those involving intrusion [10] probably can be ruled out because they should produce sharp outer boundaries controlled by faults. Two new models can be posed based on the Galileo data; one involves cryovolcanism and the other involves a thermal wave. In the first model, the icy crust is fractured by tectonic processes, allowing explosive venting of materials onto the surface. As proposed by Crawford and Stevenson [11], explosive venting could occur on Europa if subsurface water were charged with volatiles such as CO and CO_2 [12]. We suggest that initial explosive eruptions would incorporate non-ice components derived from the ice crust during "magma" ascent; this material would collect adjacent to the vent and thin outward to form the diffuse, low-albedo margins. Some of the volatile components would be lost to space while some would condense onto the surface as frost mixed with the non-ice component. This first phase of activity could involve continuous eruptions along the fracture as "cryovolcanic fountaining" analogous to "curtain of fire" fissure eruptions observed in Hawaii;

discontinuous, local eruptions along fractures could produce geysers leading to aligned low-albedo spots, as observed along Rhadamanthys Linea. The second phase of TB formation could occur immediately after the first phase, or be separated by a hiatus in some cases. This phase reactivates the vent-fracture and involves the extrusion of water and/or ductile ice. Because the first phase essentially cleaned the fracture of non-ice components, relatively pure water or ductile ice could reach the surface with little or no low-albedo material. Upon reaching the surface, the water may freeze in place or the ductile ice may extrude to some height, depending on its viscosity and the extruding pressure. The medial depression observed on some bright ridges in C-3 data could represent additional tectonic deformation along the same zones of weakness, although it is not clear that these features are TB.

The thermal wave model also involves initiation by the formation of a fracture in the icy crust by tectonic processes. However, in this case, ductile, warmer material moves into the upward-propagating crack toward the surface. As the resulting thermal wave reaches the surface, the volatile components in the surface crust sublimate, concentrating the non-ice component as a low-albedo lag deposit. The intensity of the process is greatest along the fracture zone and decreases outward, accounting for the diffuse outer margins. Alternatively, the thermal wave could cause a re-crystallization of the icy crust, producing a different ice grain size having a lower albedo. In either case (or a combination of lag deposits and re-crystallization), the initial phase is followed by extrusion of ductile ice along the fracture to produce the bright medial band. In this model, discontinuous deposits of the low albedo component and irregularities in the medial ridge are explained by variations in the intensity of the thermal wave.

Subsequent observation of TB in high resolution will be made on orbits E-6 and E-11. These data will allow for testing of these models of TB formation, or lead to the derivation of new models.

References

[1] Smith et al., 1979a, *Science*, *204*, 951. [2] Smith et al., 1979b, *Science*, *206*, 927. [3] Clark et al., 1996, *Capistrano Confr*. *5*, 22. [4] Lucchitta and Soderblom, 1982, Univ. Ariz. Press. [5] Malin and Pieri, 1986, Univ. Ariz. Press. [6] Belton et al., 1996, *Science*, *274*, 377. [7] Greeley et al., 1996, *Capistrano Confr*. *5*, 32. [8] Golombek and Bruckenthal, 1983, *LPSC*, *14*, 251. [9] Buratti and Golombek, 1988, *Icarus*, *75*, 437-449. [10] Finnerty et al., 1981, *Nature*, *289*, 24. [11] Crawford and Stevenson, 1988, *Icarus*, *73*, 66. [12] Fagents and Greeley, 1997, This issue.